A Comparison of the Surface Properties of CAD/CAM and Conventional Polymethylmethacrylate (PMMA)

Al-Dwairi, Ziad N ; Tahboub, Kawkab Y ; Baba, Nadim Z ; Goodacre, Charles J ; Özcan, Mutlu

Abstract: Purpose To compare surface properties of 2 brands of pre-polymerized resin blocks for complete dentures (CAD/CAM PMMA) to conventional heat-polymerized PMMA. Materials and Methods A total of 45 rectangular specimens (25 × 25 × 3 mm) were fabricated from 3 brands of PMMA (n = 15/group): AvaDent CAD/CAM PMMA, Tizian-Schütz CAD/CAM PMMA, Meliodent conventional PMMA. Specimens were examined for wettability using the sessile drop method, surface roughness using a digital contact profilometer, and microhardness using Vickers hardness number. Statistical analysis was performed using one-way ANOVA and Tukey pairwise multiple comparisons. p-Values of 0.05 were considered significant. Results AvaDent specimens demonstrated the highest mean contact angle (72.87 ± 48°) and the highest mean Vickers hardness number (20.62 ± 0.33). The conventional heat-polymerized specimens showed the highest mean surface roughness (0.22 ± 0.071 m). Tizian-Schütz specimens showed the lowest mean surface roughness (0.12 ± 0.02 m). Conclusions As CAD/CAM PMMA groups exhibited significantly more favorable surface properties in comparison to the conventional heat-polymerized groups, CAD/CAM dentures are expected to be more durable. Different brands of CAD/CAM PMMA may have inherent variations in surface properties.

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Title

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Running Title

Surface Properties of CAD/CAM and PMMA

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ABSTRACT

Purpose: To compare surface properties of 2 brands of pre-polymerized resin blocks for complete dentures (CAD/CAM PMMA) to conventional heat-polymerized PMMA.

Materials and Methods: A total of 45 rectangular specimens (25 x 25 x 3 mm) were fabricated from 3 brands of PMMA (n = 15/group): AvaDent CAD/CAM PMMA, Tizian-Shütz CAD/CAM PMMA, Meliodent conventional PMMA. Specimens were examined for wettability using the sessile drop method, surface roughness using a digital contact profilometer, and microhardness using Vickers hardness number. Statistical analysis was performed using one-way ANOVA and Tukey pairwise multiple comparisons. *P*-values of ≤ 0.05 were considered significant.

Results: AvaDent specimens demonstrated the highest mean of contact angle (72.87 ± 48°) and the highest mean of Vickers hardness number (20.62 ± 0.33). The conventional heat-polymerized specimens showed the highest mean of surface roughness (0.22 ± 0.071 µm). Tizian-Schütz specimens showed the lowest mean of surface roughness (0.12 ± 0.02 µm).

Conclusions: As CAD/CAM PMMA groups exhibited significantly more favorable surface properties in comparison to the conventional heat-polymerized groups, CAD/CAM dentures are expected to be more durable. Different brands of CAD/CAM PMMA may have inherent variations in surface properties.

Keywords: CAD/CAM; complete denture; dentures; PMMA; polymethylmethacrylate; surface properties.

Complete dentures still represent the only convenient treatment option for a considerable percentage of patients.[1,2] Therefore, the ideal denture base material should have superior surface and mechanical properties.[3] Walter Wright introduced acrylic resin -

polymethylmethacrylate (PMMA) - to the market in 1936. It became the most popular denture base material[4,5] and gained increased popularity due to its ease of handling and manipulation, lack of toxicity, good esthetic results, adequate strength, ease of reparability, stability in the oral environment, low solubility, reasonable cost, and low water sorption.[6,7] However, the mechanical properties of PMMA have been considered inadequate.[4,8] Among the common drawbacks of PMMA are dimensional changes, susceptibility to fracture, residual monomers, and increased risk of denture-associated infections.[8,9] In addition, there is a possibility of surface and subsurface voids, which can not only jeopardize the mechanical properties of the processed denture but also compromise esthetic and hygienic results.[10]

Surface characteristics of acrylic dentures such as roughness, hardness, and wettability have been reported to be key players in denture-associated stomatitis.[9,11-13] Surface roughness has been described as “little indentations or irregularities that characterizes a surface and has its influence on wetting, quality of adhesion, and brightness of that surface.”[14] Rough surfaces tend to induce halitosis[5] and are considered more vulnerable to discoloration than smooth surfaces, thereby reducing patient comfort.[14] As microbial adhesion and colonization usually occur on nonshedding surfaces,[15] dental prostheses need to have smooth surfaces to minimize the retention of plaque and microorganisms.[11,14] To decrease the accumulation and colonization of microorganisms, the surface roughness of dental prostheses should not exceed a threshold of 0.2 μm.[1,5,16] Studies reported that a 0.2 μm roughness threshold can be achieved by common laboratory and chairside finishing and polishing procedures.[17] Therefore, adequate finishing and polishing of dental prostheses, including dentures, are mandatory to minimize prosthesis surface roughness.[16] Zissis et al[17] evaluated the surface roughness of commercially available denture base materials, including soft and hard relining materials, and reported the overall surface roughness to be between 0.7 and 7.6 μm.

Surface wettability is an indicator of the ability of saliva and other liquids to easily spread over a surface and reflects the amenability to allow or prevent adherence of fluids to prosthetic surfaces and dental materials.[18] Ultimate wettability, for example, is needed for fixed restoration cementation and retention of removable dentures.[19] On the other hand, wettability can be troublesome in favoring staining, microorganisms, and plaque adhesion on oral prostheses.[16,19,20]

Surface hardness is defined as "the ability of a material's surface to resist permanent penetration or indentation."[21] In addition to being sensitive to monomer levels, it has been reported that there is a correlation between surface hardness and a material's mechanical properties.[3] For example, the amenability of acrylic-polymer to degradation makes it vulnerable to fracture and aggravates the chance of plaque, microorganism, and pigment retention, eventually jeopardizing the denture base longevity.[22]

Computer-aided design/computer-aided manufacturing (CAD/CAM) techniques have expanded recently to embrace the fabrication of complete dentures, record bases, immediate dentures, and implant-supported overdentures in 2 clinical appointments.[23] As CAD/CAM dentures are milled from pre-polymerized PMMA billets that are polymerized under high temperatures and pressure values, CAD/CAM dentures are reported to be less porous, and consequently, less likely to harbor virulent microorganisms such as *Candida albicans,* which will be less able to adhere to the surface of digital dentures.[24] Accordingly, CAD/CAM dentures provide a promising treatment option for patients at risk of *Candida* fungal infection; however, the authors know of no published reports that have investigated the surface properties of CAD/CAM PMMA. The null hypotheses of the study were that no differences would be found between the surface properties of CAD/CAM PMMA and conventional heat-polymerized PMMA nor between different brands of available CAD/CAM PMMA.

MATERIALS AND METHODS

Two brands of CAD/CAM PMMA billets were used in this study: AvaDent PMMA billets (Global Dental Science, Scottsdale, AZ) and Tizian Blank PMMA (Shütz Dental, Rosbach vor der Höhe, Germany). Four billets (98 mm diameter × 25 mm thick) were needed from each brand to mill the CAD/CAM PMMA specimens.

A plexiglass (Year Long Industrial Co. Ltd, Tainan City, Taiwan) specimen measuring 25 × 25 × 3 mm was sprayed with a contrast spray (mega Okklusions Spray EXACT; megadental Gmbh, Büdingen, Germany), stabilized on a custom-made stone base, and mounted in Ceramill map 400 CAD/CAM scanner (Amann Girrbach AG, Koblach, Austria). The digital image of the scanned specimen was processed using Ceramill mind1.0 software (Exocad GmbH, University of Chicago, IL).

PMMA billets were milled according to the provided design using TIZIAN Cut 5 Smart Plus open CAD/CAM milling system, (Shütz Dental). Thereafter, milled specimens were cut from the billets and finished using tungsten carbide acrylic burs (Edenta, Au, Switzerland) and silicon carbide papers (Schmirgelleinen; megadental). The specimens were further polished using rubber acrylic burs (Edenta), pumice (Shera, Lemförde, Germany), and rouge (Dialux, Paris, France). Polishing was performed for one surface only while the other surface remained untouched in order to mimic denture tissue surfaces as much as possible.[9] All specimens were prepared and polished by the same operator. Specimen dimensions were verified using a digital caliper (Mitutoyo Corp., Tokyo, Japan). Specimens were stored in distilled water for 48 hours to eliminate residual monomers.[9]

Conventional heat-polymerized PMMA specimen fabrication

CAD/CAM PMMA specimens measuring 25 × 25 × 3 mm were coated with 2 layers of Vaseline (Beirut Co., Damascus, Syria) then invested in vacuum-mixed type III dental stone (Elite Model; Zhermack, Badia Polesine, Italy) and a vacuum-mixed 50:50 mixture of dental stone and dental plaster (Al khayyat dental plaster, Yanbu, Saudi Arabia). Flasking was done in a two-part mold using a Hanau Varsity Flask (Hanau Engineering Co., Buffalo, NY). The flasks were opened, and the PMMA patterns were removed. The surfaces of the rectangular cavities were sealed with 2 coats of Cold Mold Seal (PSP, Kent, UK) sealant. Heat-polymerized acrylic resin (Meliodent, Heraeus Kulzer, Hanau Germany) powder and liquid were proportioned and mixed according to manufacturer instructions. The dough was packed under pressure then polymerized using a short curing cycle in a thermostatically controlled water bath (Type 5518; KaVo EWL, Biberach, Germany), according to manufacturer instructions.

Excess acrylic was trimmed and specimens were finished and polished exactly as done for the CAD/CAM PMMA specimens. Specimen dimensions were verified using a digital caliper (Mitutoyo Corp.). Likewise, specimens were stored in distilled water for 48 hours to minimize residual monomers.[25]

For each study group, 15 specimens measuring 25 × 25 × 3 mm were used to perform the following surface tests (Fig 1).

Surface wettability

The sessile drop method was used to measure the angle formed by distilled water on the PMMA surface.[26] A 20-µl distilled water drop was delivered from a micropipette (Transferpette S; Sigma Aldrich, Darmstadt, Germany) on the polished surface of a horizontally placed specimen on a previously tested horizontal bench.[27] The water drop was left to spread for 20 seconds, and at that moment, a Canon EOS 60D camera (Canon, Melville, NY) with a 105 mm Sigma micro-lens (Sigma Corp., Kanagawa, Japan) was used to capture an image. The camera was fixed to its tripod throughout the procedure. Specimens were placed on a previously marked position, which guaranteed fixed setting each time. The image was then imported and analyzed using AutoCAD 2010 software. The angle (ø) between the solid line of the specimen and the tangent to the water drop was measured on the right and left sides, and the average was recorded.[9]

Surface roughness

After bench drying, the specimens were tested for surface roughness using a digital contact profilometer (RT-10, SM S.R.L, Italy) with a resolution of 0.001µm and a total measurement length of 0.8 mm. Four Ra readings on different areas with similar positions on each polished surface of the specimens were taken and the average was calculated.[9]

Surface hardness

Vickers hardness number (VHN) was used to determine the surface hardness for the specimens directly after removal from the distilled water. A Micro Hardness Tester (Model MHT-1, No.8621; Matsuzawa Seiki Co. LTD., Tokyo, Japan) was used with a square-based pyramid indenter under a 300 g load at 15-second dwell time.[9] Three indentations were performed for each specimen. Afterwards the pyramids were analyzed, and the resulting diagonals were measured to calculate the VHN (Fig 2). The average for the three VHNs was calculated.

Statistical analysis

Individual contact angle, surface roughness, and VHN values were calculated and tabulated. Minitab 17 computer software (Minitab Inc. State College, PA) was used to calculate the means and the standard deviations for each test. Afterward, one-way ANOVA was used to determine whether significant differences existed among the study groups (AvaDent, Tizian-Shcütz, and the conventional heat-polymerized groups), followed by Tukey-pairwise multiple comparisons. A P value of ≤ 0.05 was considered significant. The non-parametric test (Kruskal-Wallis) was used in case considerable variations in values of surface properties were noticed.

RESULTS

Contact angles

Means and standard deviations of average contact angles are summarized in Table 1. AvaDent specimens demonstrated the highest mean contact angle (72.87 ± 4.83°), followed by Tizian-Shcütz (69.53 ± 3.87°). The conventional heat-polymerized group showed the lowest mean of contact angle (65.97 ± 4.67°). The difference in mean angles between the AvaDent group and the conventional heat-polymerized group was statistically significant ($P <$ 0.001,F = 8.92). The mean contact angles of the Tizian-Shcütz group was not statistically significant from the AvaDent group ($P = 0.115$), or from the conventional heat-polymerized group ($P = 0.086$) (Table 2).

Surface roughness (Ra values)

Conventional heat-polymerized PMMA (Table 1) showed the highest mean surface roughness (0.22 ± 0.07 μm), followed by AvaDent (0.16 ± 0.03 μm). The Tizian-Shcütz group showed the lowest mean of surface roughness (0.12 ± 0.02 μm). The decrease in the means of the surface roughness between the three tested groups was statistically significant ($P < 0.05$, F = 18.03) (Table 2).

Surface hardness

The highest mean of VHN was recorded for the AvaDent group (20.62 ± 0.33) followed by the Tizian-Schütz group (19.80 ± 1.08) and the conventional heat-polymerized group (18.09 ± 0.31) (Table 1). Both Kruskal-Wallis and ANOVA methods showed that the 3 groups differed in hardness means. Tukey pairwise comparisons revealed that these differences are statistically significant. (P <0.05; F = 53.72) (Table 2).

DISCUSSION

Manufacturers claim that CAD/CAM dentures possess superior fit, surface characteristics, and mechanical properties in comparison to conventional heat-polymerized dentures. The null hypotheses of this study that no significant differences would be found in surface properties between CAD/CAM PMMA and conventional heat-polymerized PMMA nor between different brands of CAD/CAM PMMA was rejected; CAD/CAM PMMA demonstrated significant superiority in surface wettability, surface roughness, and surface hardness. Different CAD/CAM PMMA brands might have variable surface properties. Improved surface properties in the CAD/CAM groups may be attributed to the unique processing method of the CAD/CAM PMMA billets in which high temperatures and pressure values are used for CAD/CAM PMMA polymerization.[14]

The calculated mean of contact angles of the conventional heat-polymerized specimens in this study (65.97°) was close to the mean angle obtained by Al-Dwairi et al in their 2012 study (64.6°).[9] Zissis et al[26] measured the equilibrium contact angles of different acrylic denture base materials in addition to soft and hard relining materials and reported that the range of contact angles was between 63.9 and 81.0°. All contact angles obtained in this study were in line with the results of the aforementioned study. Murat et al[28] reported a higher contact angle, and consequently, higher hydrophobicity of conventional heat-cured PMMA when compared to CAD/CAM PMMA. The results they obtained were attributed to the effect of thermal cycling.

On the other hand, Steinmassl et al[29] reported that CAD/CAM PMMA were significantly more hydrophilic than their heat-polymerized PMMA counterparts. The increased values of contact angles among the CAD/CAM PMMA groups might be attributed to inherent characteristic features of their surfaces. It has been reported that surface energy can be affected by the surface topography, charge, and chemical composition as well as by the acquired salivary pellicle.[20] Increased hydrophobicity[16,19,20] of CAD/CAM PMMA as well as PMMA water sorption[10] might have an impact on the amenability of CAD/CAM dentures to retain stains, plaque, and microorganisms. The contact angle is the product of the balance between interfacial and surface forces. Small contact angles are associated with more water spread, increased wettability, increased hydrophilicity of the PMMA surface, and therefore increased retention of removable dentures.

Properly polished acrylic dentures and smooth dentures are more likely to succeed intraorally, given that denture base roughness has been related to its vulnerability to retain stains, plaque, and microorganisms.[30] Because surface roughness of denture base materials was reported to be influenced by the inherent properties of the material itself, polishing techniques, and the manual skills of the operator, one operator was responsible for preparing and finishing all the specimens in this study.

Recorded roughness values of the test groups in the current study were lower than the range reported by Zissis et al.[17] Previous studies reported significant increase in plaque retention and microorganism adherence to restorative materials when the R_a of these materials exceeds 0.2 µm.[20] Lower *Candida* adherence is expected for AvaDent and Tizian-Shcütz groups, which demonstrated R_a values around 0.1 µm. Both of the CAD/CAM PMMA groups showed lower surface roughness values in comparison to the conventional heat-polymerized group ($P < 0.05$), which supports Bidra et al's claim that CAD/CAM PMMA has better surface properties, less porosity, and eventually less microbial adherence. Likewise, enhanced surface characteristics of CAD/CAM PMMA might be attributed to the unique manufacturing process of these materials; reduced levels of residual monomers as well as the polymerization method involved in PMMA manufacturing were previously reported to contribute to surface roughness alteration.[32] The results of the present study support Murat et al's results[28] of lower R_a values for the CAD/CAM PMMA group using a contact type profilometer and the results of Steinmassl et al,[29] who tested different complete dentures of variable CAD/CAM PMMA brands and compared them to conventional dentures and reported significant lower roughness values for the CAD/CAM groups.

Srinivasan et al[33] recently reported no statistical difference between surface roughness of conventionally cured PMMA and CAD/CAM PMMA; however, in their study they used manual table saws to cut the specimens, instead of a milling system, which might have an effect on comparing surface roughness values. Moreover, a non-contact laser profilometer was used to detect R_a values in the aforementioned study. Arslan et al[34] recently found that the hydrophobicity of CAD/CAM PMMA-based polymers was higher than the conventional heat-polymerized PMMA, whereas the CAD/CAM PMMA-based polymers had R_a values similar to the conventional PMMA.

In the present study, CAD/CAM PMMA groups exhibited higher surface hardness than the conventional heat-polymerized group did, which might support the manufacturer's claim of lower levels of residual monomers in CAD/CAM PMMA. In 2012, Farina et al reported that homogenous heating of PMMA yielded higher monomer conversion, minimized the plasticizing effect of residual monomers, and consequently increased surface hardness.[22]

Although the results of the present study reported differences in surface properties between CAD/CAM and conventional dentures, the choice between digitally milled and conventional dentures may also be influenced by processing time and cost; however, a recent survey in US dental schools evaluated digital dental fabrication in pre- and postdoctoral education reported found that in US programs, the percentage of CAD/CAM complete denture fabrication out of the total number of fabricated complete dentures approached 10%, and the majority of respondents program directors are planning to include CAD/CAM dentures to their curricula within a period of 1 to 4 years. Accordingly, the anticipated spread of CAD/CAM dentures will positively raise the level of education, investigation, and the evaluation of the different clinical scenarios since these dentures are entirely digitally manufactured.[35]

CONCLUSIONS

1- CAD\CAM PMMA groups exhibited significantly higher surface hardness and hydrophobicity in comparison to the conventional heat-polymerized group.
2- Different CAD/CAM PMMA brands might have variable surface hardness, surface roughness, and wettability.

3- The AvaDent CAD/CAM PMMA group demonstrated the highest surface hardness (VHN), while the Tizian-Schütz group registered the lowest R_a value for surface roughness. No significant differences among the 2 groups were found for contact angle.

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Table 1: Means and standard deviations for the performed tests

	AvaDent		Schütz		Conventional heat-polymerized	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Contact angle (degrees)	72.87	4.83	69.53	3.87	65.97	4.67
Surface roughness (µm)	0.16	0.03	0.12	0.02	0.22	0.071
Surface hardness (VHN)	20.60	0.33	19.80	1.08	18.09	0.31

	AvaDent & conventional heat-polymerized		Conventional heat polymerized & Tizian-Schütz		Tizian-Schütz & AvaDent	
	t-value	p-value	t-value	p-value	t-value	p-value
Surface wettability	-4.22	<0.001	2.18	0.086	-2.04	0.115
Surface roughness	3.50	0.003	-6.00	<0.001	-2.65	0.031
Surface hardness	-10.14	<0.001	6.93	<0.001	-3.21	0.007

Table 2: P-values and t-values for the performed tests

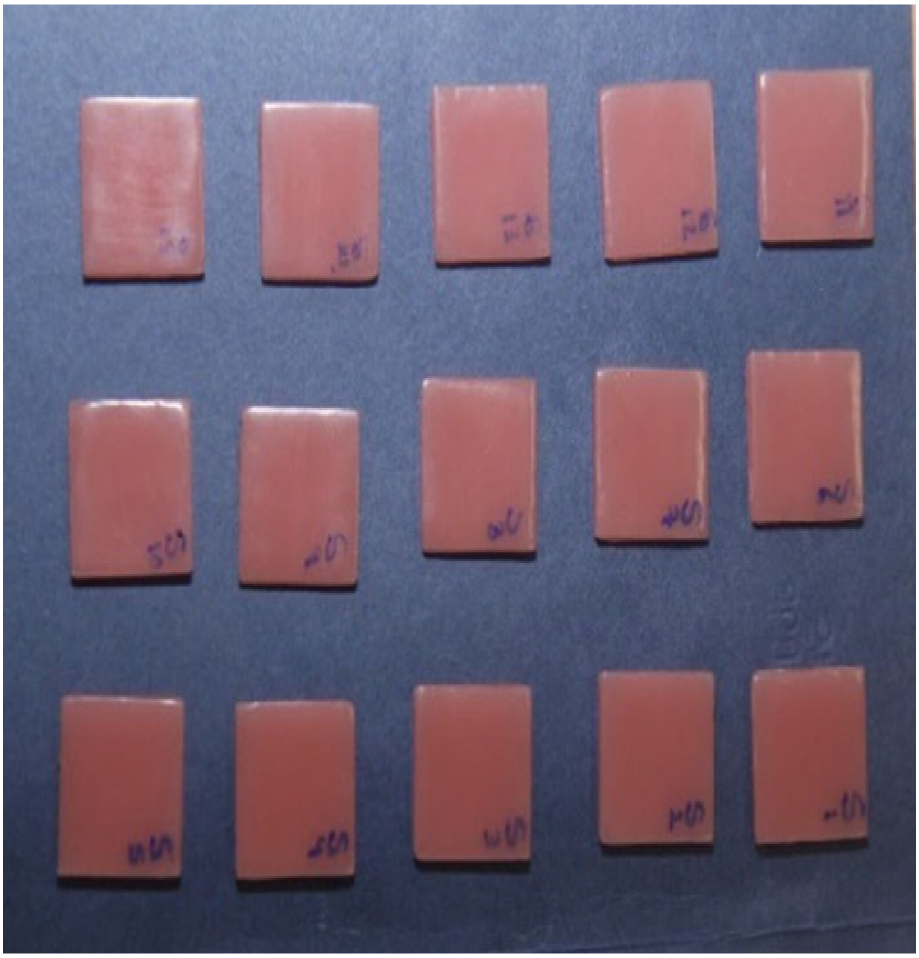

Figure 1 (A) AvaDent specimens

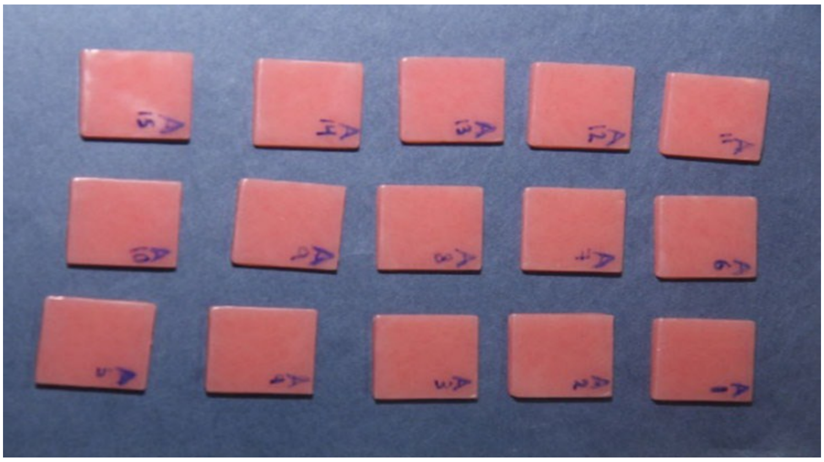

Figure 1 (B) Tizian-Schütz specimens

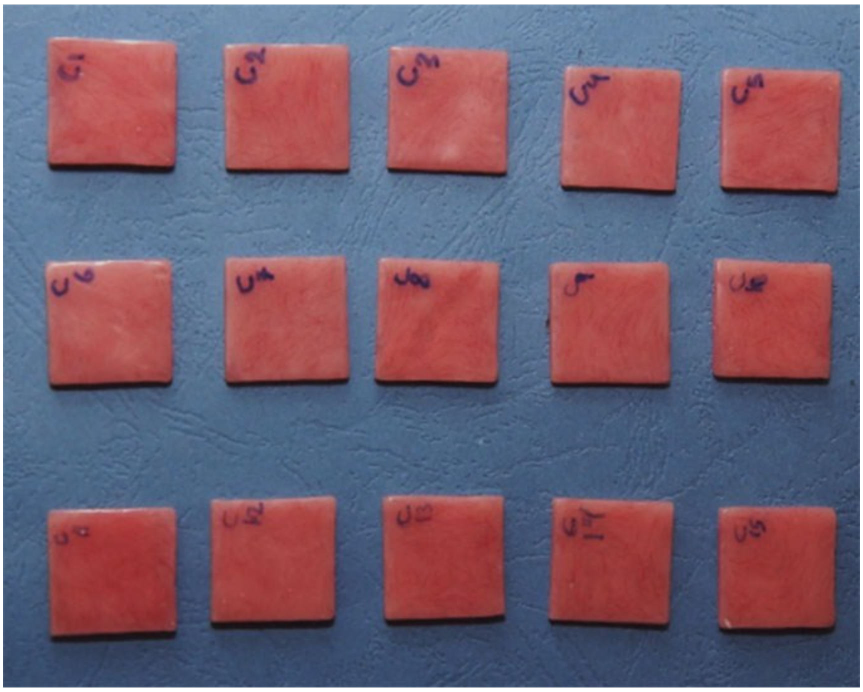

Figure 1 (C) Conventional heat-polymerized specimens

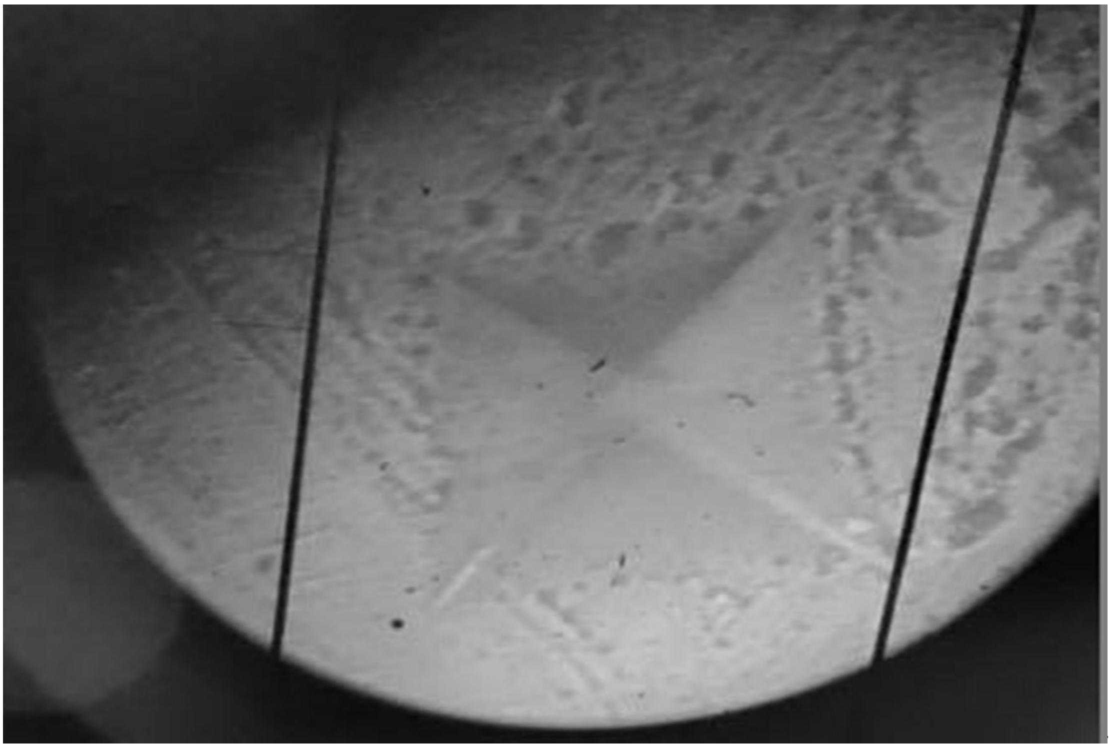

Figure 2 (A) Microharness testing and pyramids' diagonal measurements: (A) Tizian-Schütz specimen

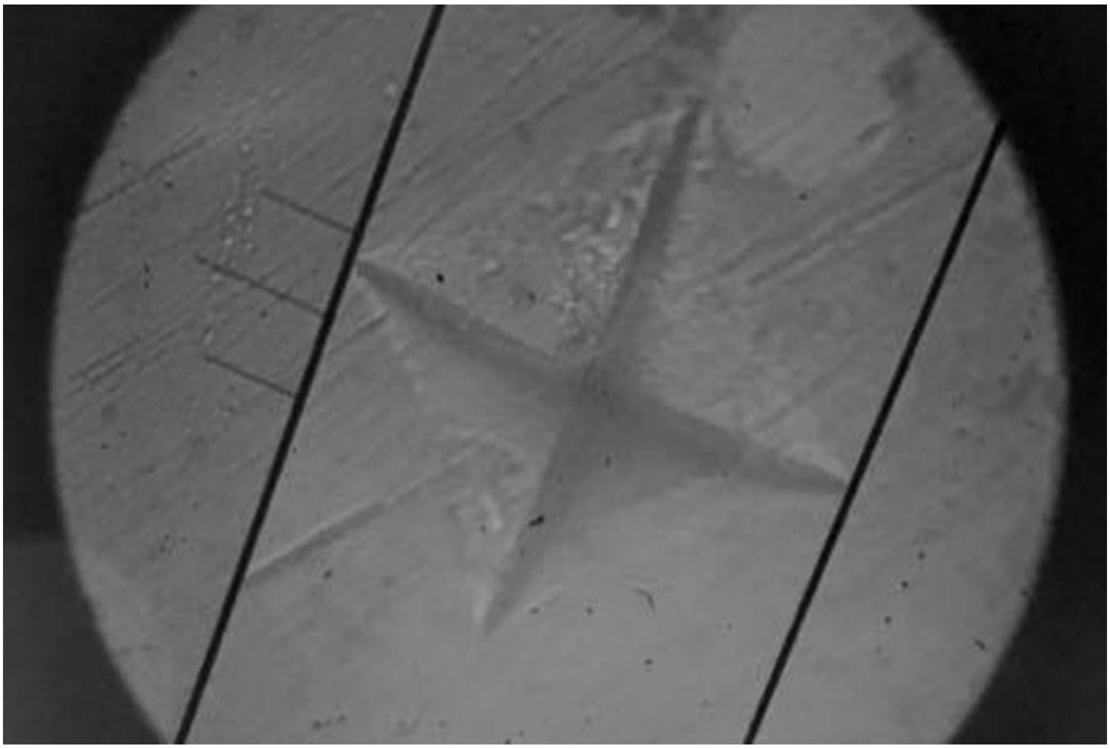

Figure 2 (B) Microhardness testing and pyramids' diagonal measurements: (B) Conventional heat-polymerized specimen

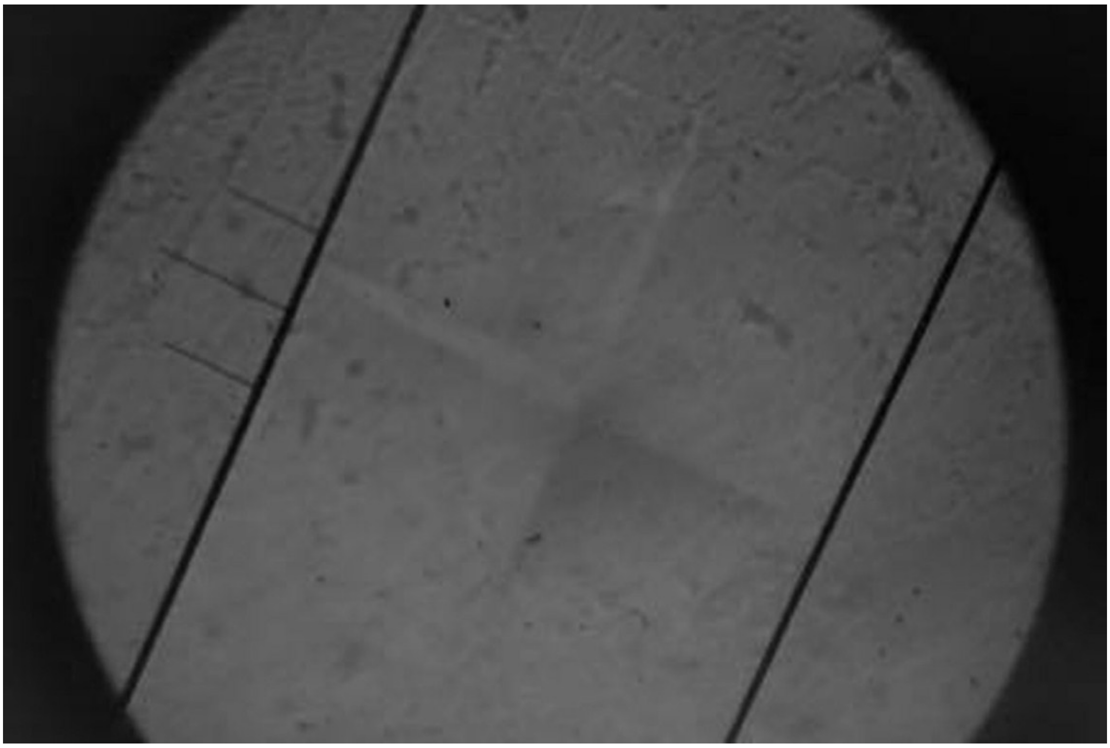

Figure 2 (C) Microhardness testing and pyramids' diagonal measurements: (C) AvaDent specimen